Performance, Facility Pressure Effects, and Stability Characterization Tests of NASA's Hall Effect Rocket with Magnetic Shielding Thruster

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Outline

- Motivation
- HERMeS TDU-1 Hall Thruster
  - Conducting and dielectric front pole cover configurations
  - Electrical configurations
- Test Facility
- Result & Discussion
  - Performance & stability characterization
  - Facility pressure effects characterization
- Summary

Motivation

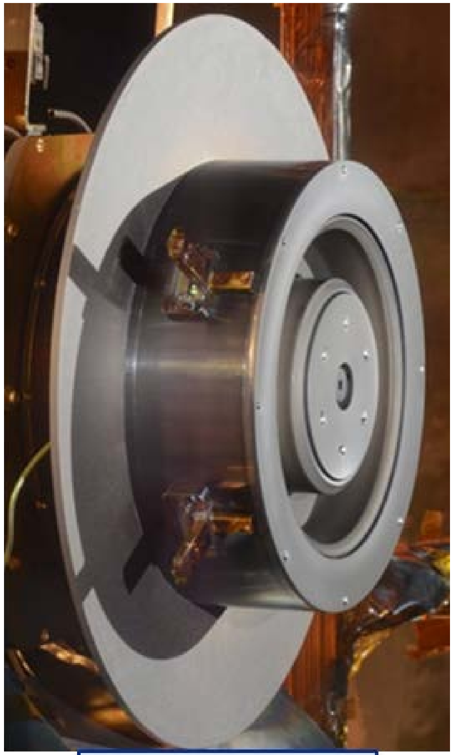
- This paper presents a subset of the data that was collected on the HERMeS TDU-1 thruster prior to performing an extended duration test to assess the wear mechanism in TDU-1
- The wear, stability, and performance of the thruster are key criteria for finalizing the thruster ground test configuration
- This paper presents results from detailed performance and stability analysis of two thruster configurations
  - This data is needed to help with selecting configuration for the thruster wear test configuration
- This paper also assessed thruster performance and stability at different facility background pressure conditions to help elucidate how thruster will operate and perform in a “zero” pressure environment

Accompanying Papers

- W. Huang, “Facility Effect Characterization Test of NASA’s HERMeS Hall Thruster,” AIAA-2016-4828, 98-EP-15, 7/26 @ 17:00
- W. Huang, “Plasma Oscillation Characterization of NASA’s HERMeS Hall Thruster via high Speed Imaging,” AIAA-2016-4829, 98-EP-15, 7/26 @ 17:30
- J. Myers, “Hall Thruster Thermal Modeling and Test Data Correlation,” AIAA-2016-4535, 11-EP-1, 7/25 @ 11:00
- J. Gilland, “Carbon Back Sputter Modeling for Hall Thruster Testing,” AIAA-2016-4941, 129-EP-20, 7/27 @11:00
- G. Williams, “2000-Hour Wear Testing of the HERMeS Thruster,” AIAA-2016-5025, 154-EP-24, 7/27 @15:30
- T. Sarver-Verhey, “Hollow Cathode Assembly Development for the HERMeS Hall Thruster,” AIAA-2016-5026, 7/27 @ 16:00
- P. Peterson, “NASA HERMeS’s Hall Thruster Electrical Configuration Characterization,” AIAA-2016-5027, 7/27 @16:30
- R. Conversano, “Performance Comparison of the 12.5 kW HERMeS Hall Thruster Technology Demonstration Units,” AIAA-2016-4827, 7/26 @ 16:30

TDU-1 Hall Thruster: Conducting and Dielectric Front Pole Cover Configurations

Dielectric (Al2O3)



Conducting (Graphite)

- Two front pole cover configurations were evaluated
  - Conducting (graphite pole covers)
  - Dielectric (Alumina (Al_2O_3) pole covers)

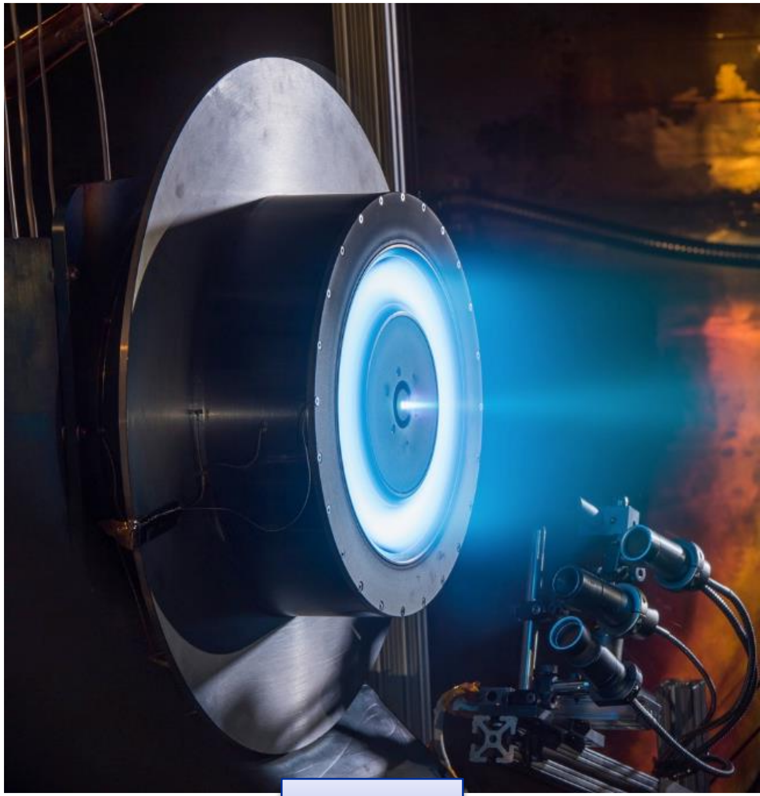
- Only the front poles were covered with a dielectric cover, remaining thruster surfaces were unaltered between the two test configurations

Electrical Configuration

- The electrical configuration of a Hall thruster, in relation to a conducting vacuum facility, has been recently identified as a concern that needs to be considered in the development and qualification of new Hall thruster propulsion systems.
- The candidate electrical configuration of a Hall thruster in a conducting ground based vacuum are:
  1. Thruster body is electrically tied to the facility ground.
  2. Thruster body is isolated from the facility ground and allowed to float with respect to the local plasma potential.
  3. Thruster body isolated from the vacuum facility chamber ground and electrically tied to the floating cathode common.
- For this test campaign two configurations were considered
  - Conducting cover with the thruster body tied to cathode
  - Dielectric (alumina-Al_2O_3)cover with the thruster body floating

HERMeS TDU-1 Hall Thruster

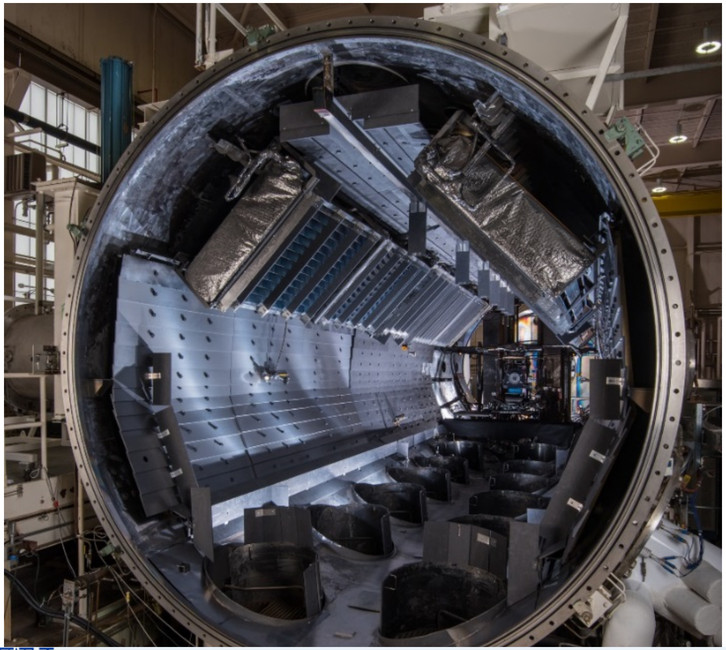
- Hall Effect Rocket with Magnetic Shielding (HERMeS)
  - 12.5 kW Hall Thruster
  - Developed by NASA GRC and JPL
  - Based on two decades of NASA Hall thruster design knowledge
  - Designed to operate up to 3,000 seconds of Isp
  - Designed to for a lifetime of >50,000 hours
- Two Technology Demonstration Units (TDU-1 & -2) Hall thrusters have been built to date
  - TDU-1 is the unit under test at NASA GRC
  - TDU-2
    - Undergone functional hot-fire tests at NASA GRC then shipped to JPL
    - At JPL TDU-2 has undergone performance characterization tests at JPL and is currently undergoing environmental testing at JPL

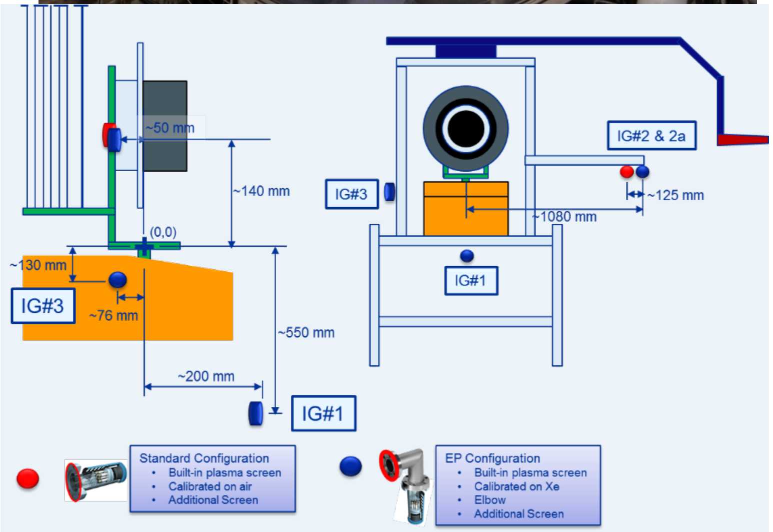


TDU-1

NASA GRC VF5

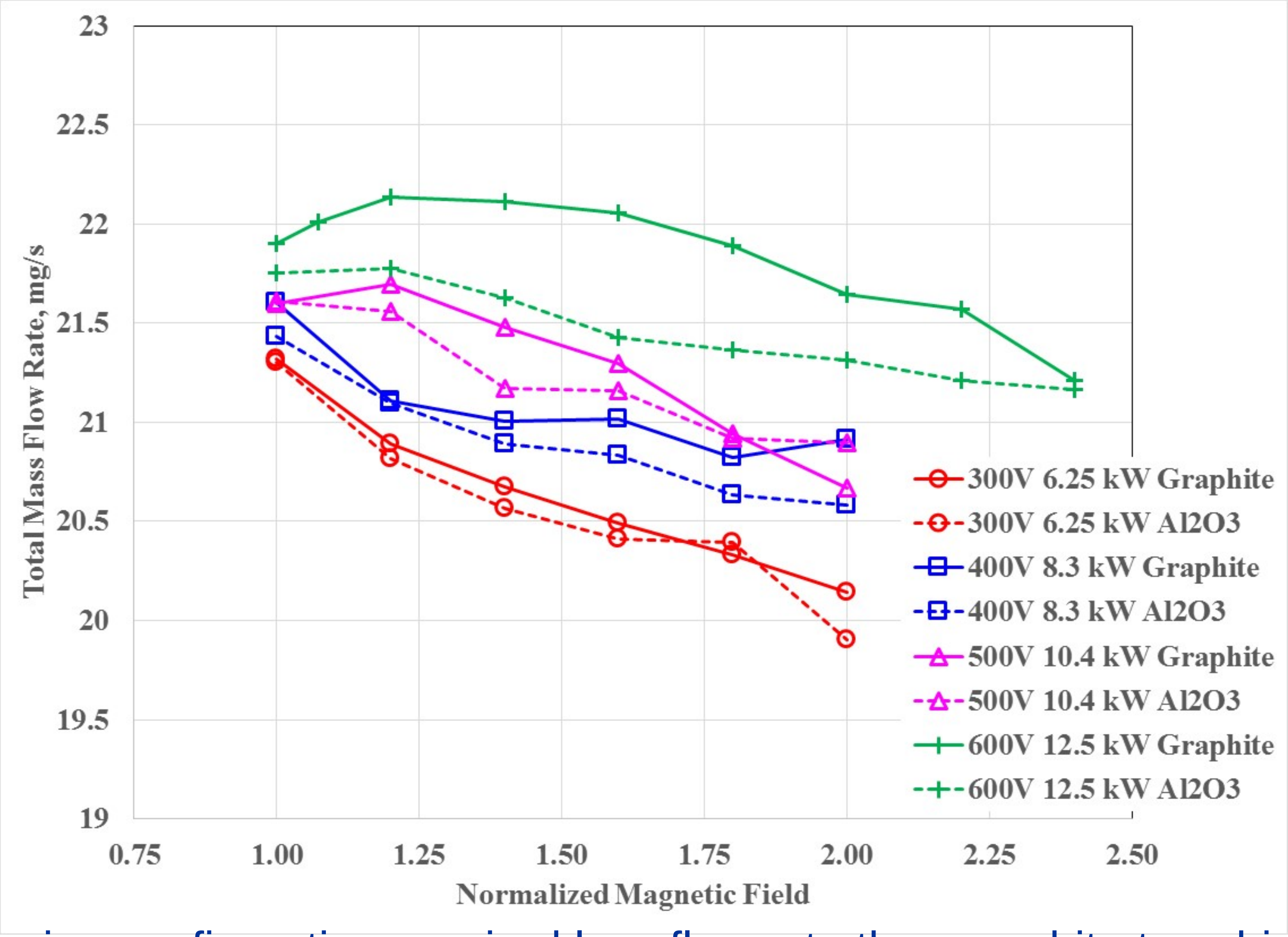
- The TDU-1 thruster testing is being performed at NASA GRC VF5
  - 15’ diameter, 60’ long that is evacuated with cryopanels
  - Facility walls lines with graphite panel to reduce backsputter rate to the thruster
  - 3 locally-located ion gauges were used to measure pressure during thruster operation
- Thruster was placed on an inverted pendulum thruster stand
- A plasma probe array was used to interrogate the thruster plume
- A QCM was used to measure the facility backsputter rate





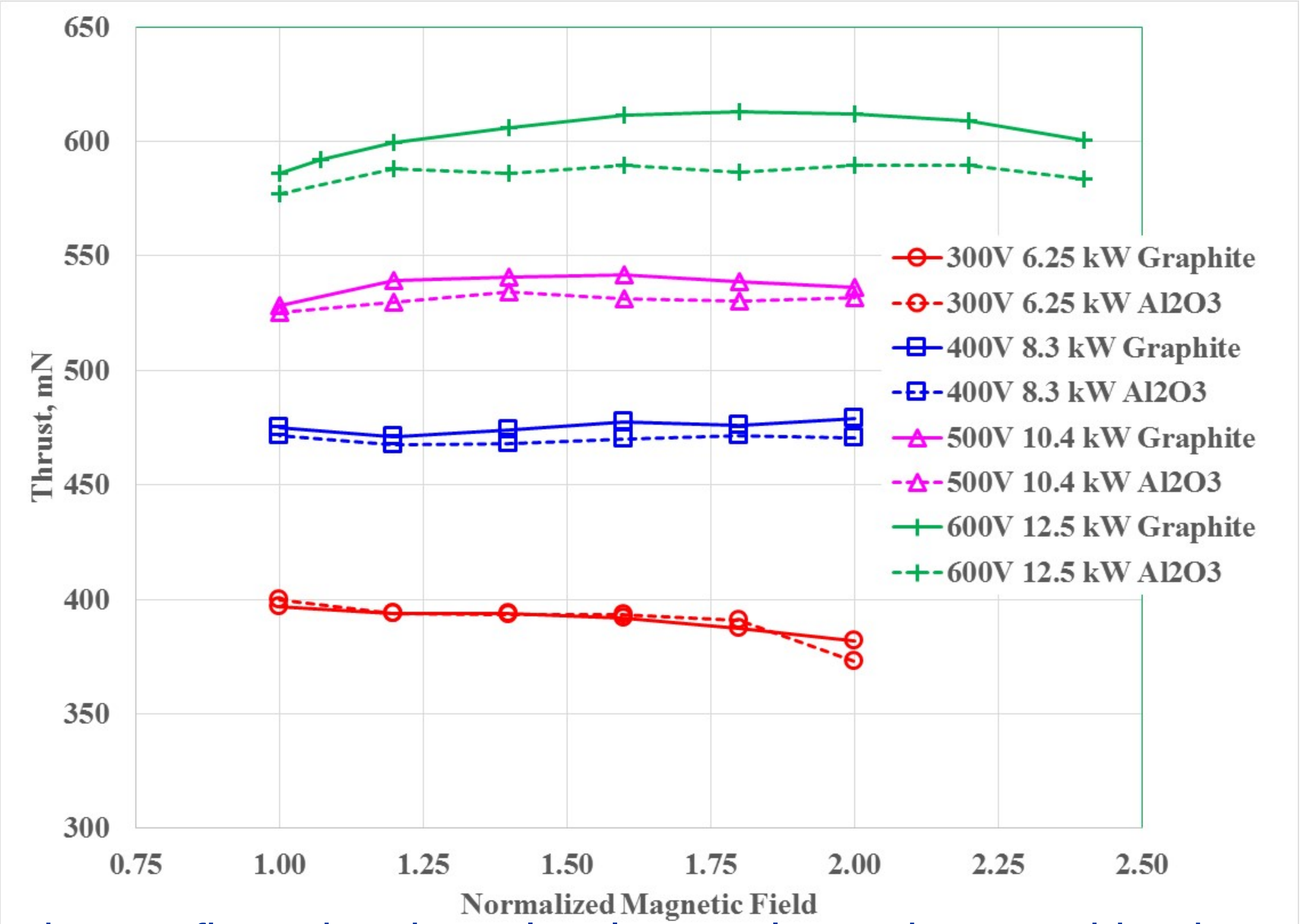
Performance Characterization

TDU-1 Performance: Anode Mass Flow Rate



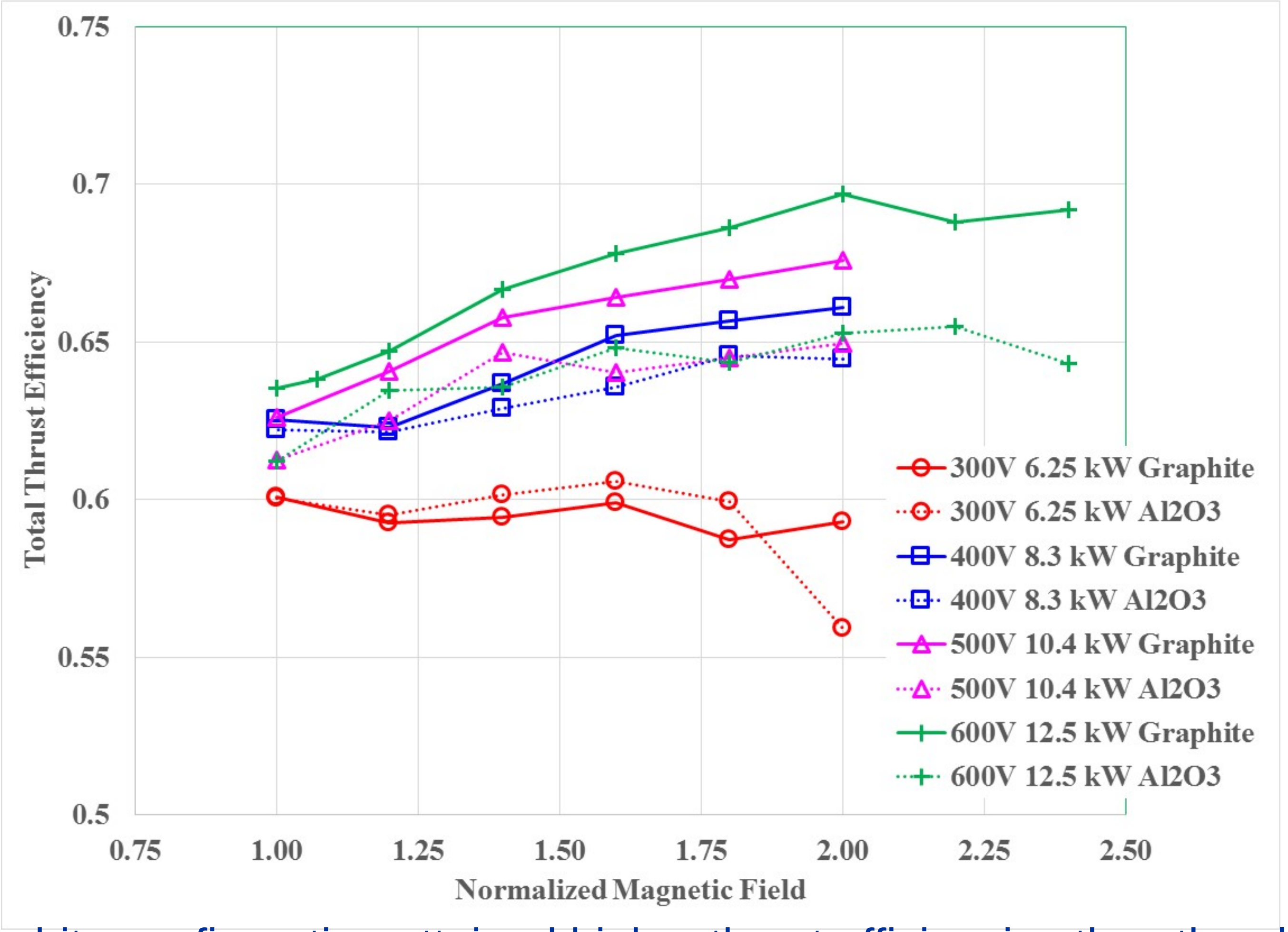
- The alumina configuration required less flow rate than graphite to achieve the same thruster discharge power
- For both thruster configurations the mass flow rate decreases with magnetic field strength

TDU-1 Performance: Thrust



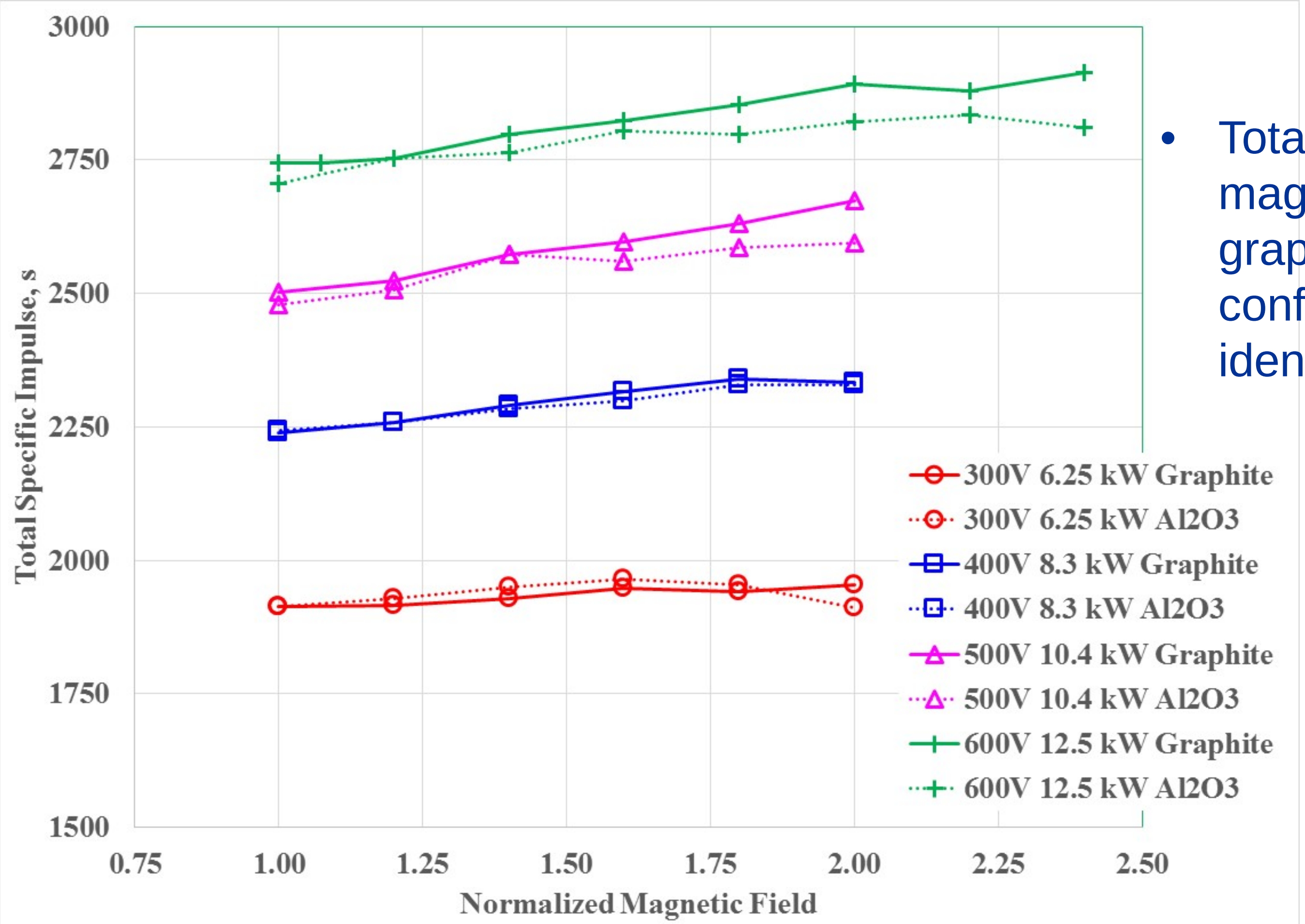
- The alumina configuration thrust levels were lower than graphite due to the lower flow rates

TDU-1 Performance: Thrust Efficiency



- The graphite configuration attained higher thrust efficiencies than the alumina at discharge voltage of 400 V and above

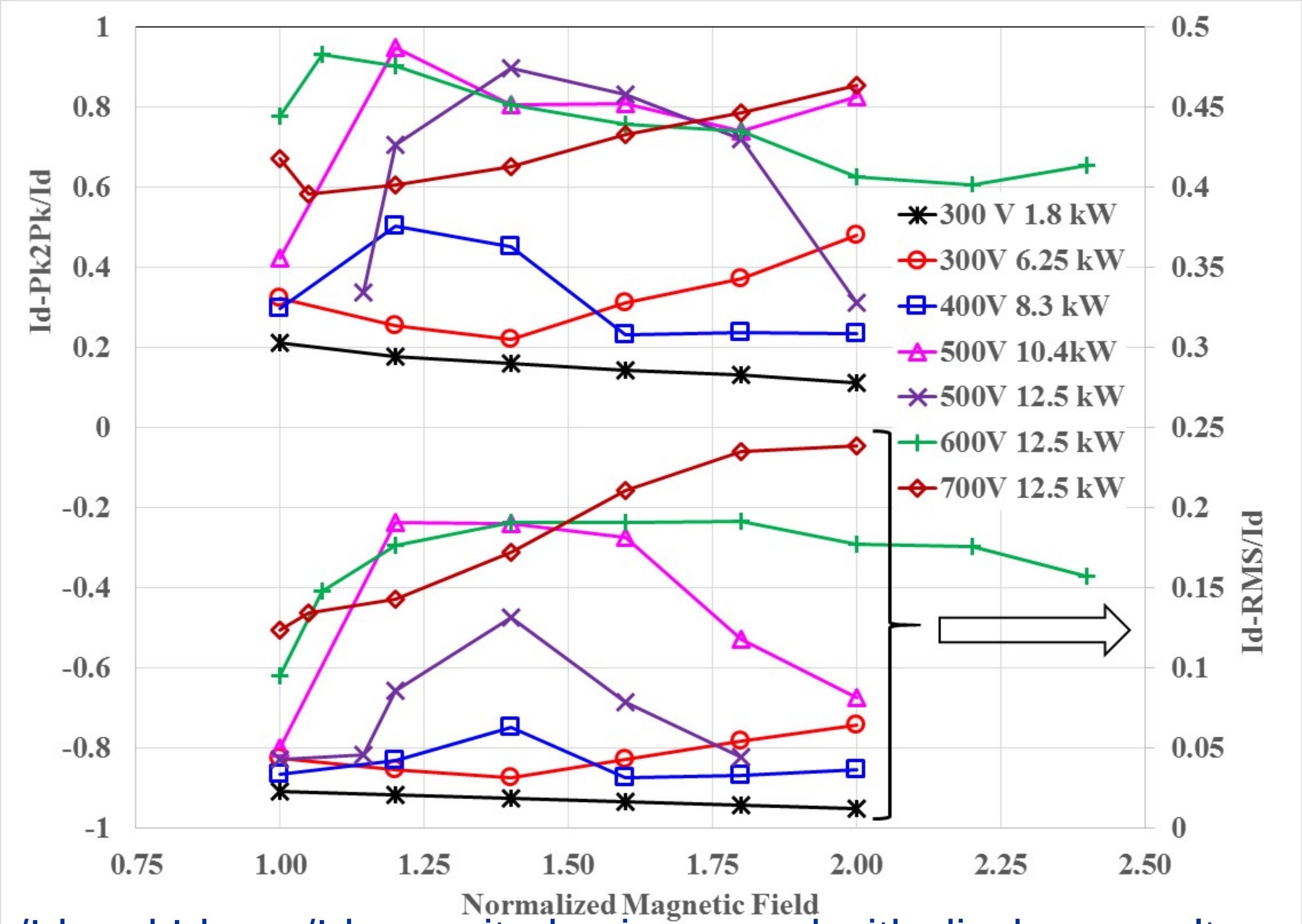
TDU-1 Performance: Specific Impulse



- Total Specific impulse magnitudes for the graphite and alumina configurations are almost identical

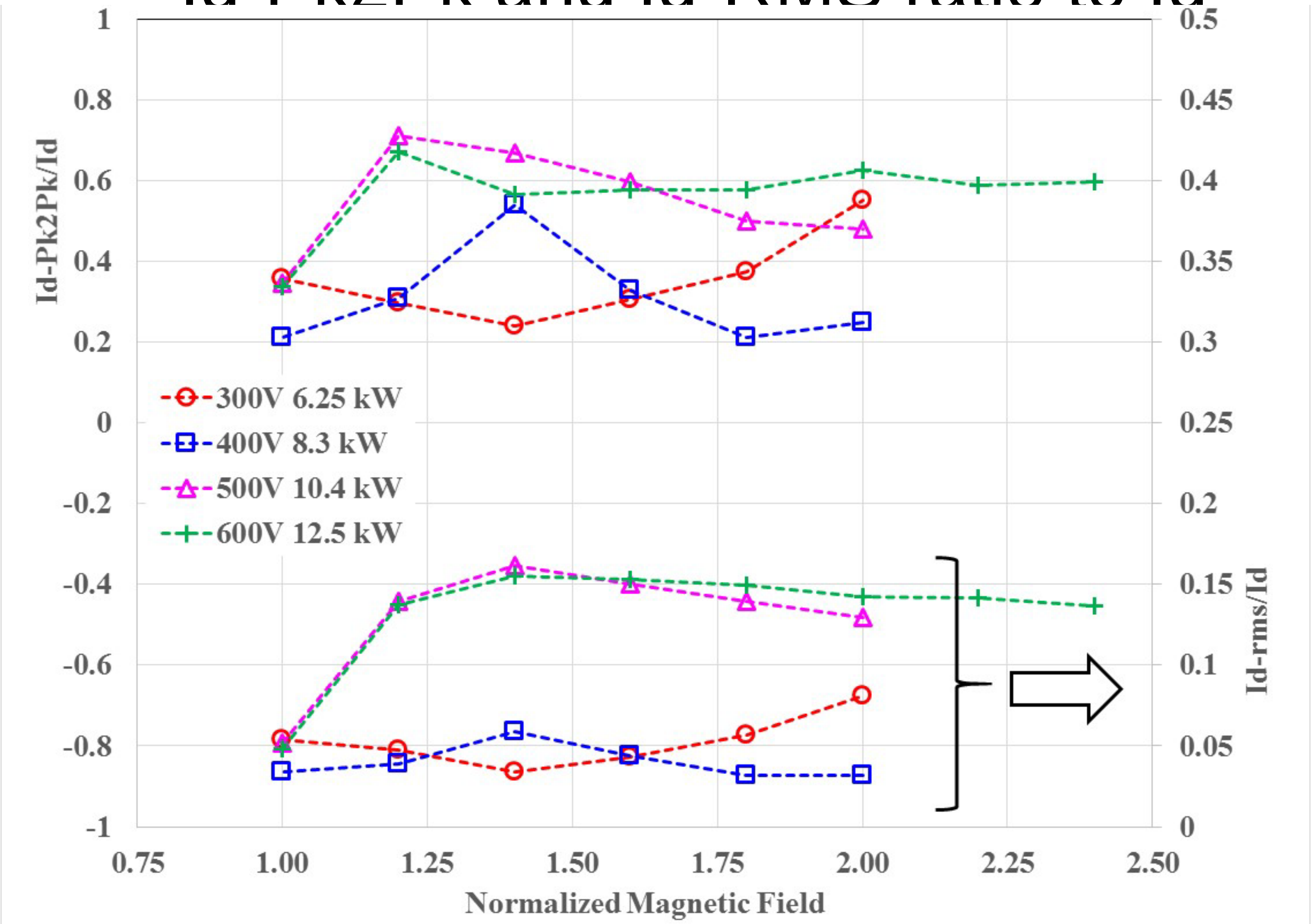
The HERMeS Thruster demonstrated reliable and efficient thruster operation for all the magnetic field settings that were evaluated thus providing a wide range of magnetic field settings to select from during space operation

TDU-1 Stability Graphite: Id-Pk2Pk and Id-RMS ratio to Id



- Id-Pk2Pk/Id and Id-rms/Id magnitudes increased with discharge voltage at a given magnetic field setting

TDU-1 Stability Alumina: Id-Pk2Pk and Id-RMS ratio to Id

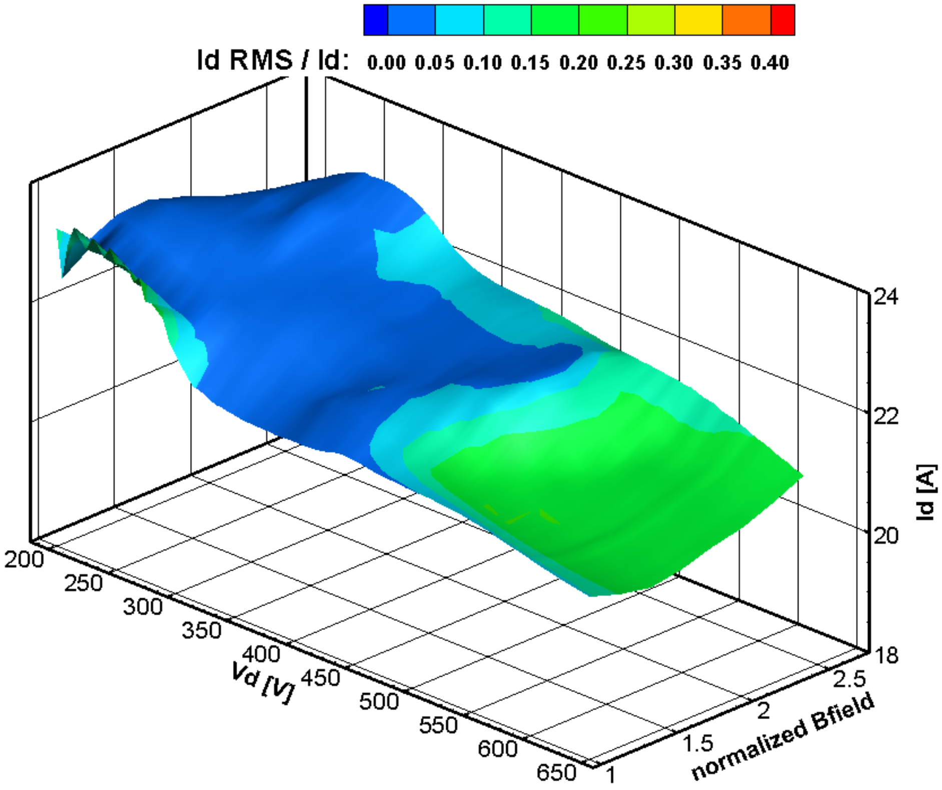


- Id-Pk2Pk/Id and Id-rms/Id magnitudes increased with discharge voltage at a given magnetic field setting
- In general slightly lower oscillation magnitudes were attained with the alumina configuration

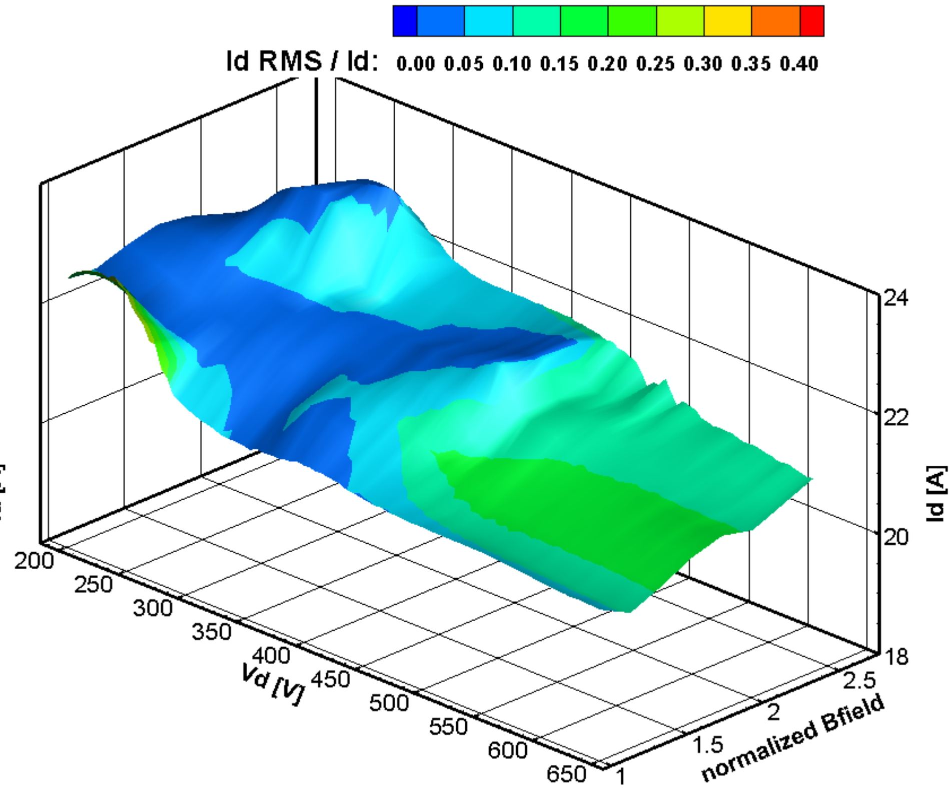
TDU-1 Summary
Graphite C-T and Alumina F Configurations

- Tests of the two candidate TDU-1 configurations indicated that the graphite C-T configuration results in higher thrust efficiency at similar specific impulse
- Tests indicated that efficient thruster performance can be attained over a wide range of magnetic field magnitudes
  - For a given operating thruster condition tests have shown that highest thrust efficiency is often attained at the highest magnetic field setting
- For both test configurations it was found the discharge current oscillations were quiescent at discharge voltages of 300 and 400 V and increased significantly at 500, 600, and 700 V
- In the graphite C-T configuration the thruster body floated to ~-10 V and the thruster body collected up to 2.3 A
  - Collected current increased with increased discharge voltage
  - It is speculated that current collection at the front poles necessitated increased anode flow and resulted in higher performance for the graphite C-T configuration
- Further analysis on the test data is being performed include Vc-g, $V_{thruster}$, I_B, and other data

TDU-1 Graphite C-T & Alumina F IVB Sweeps at ~208 & 205 sccm



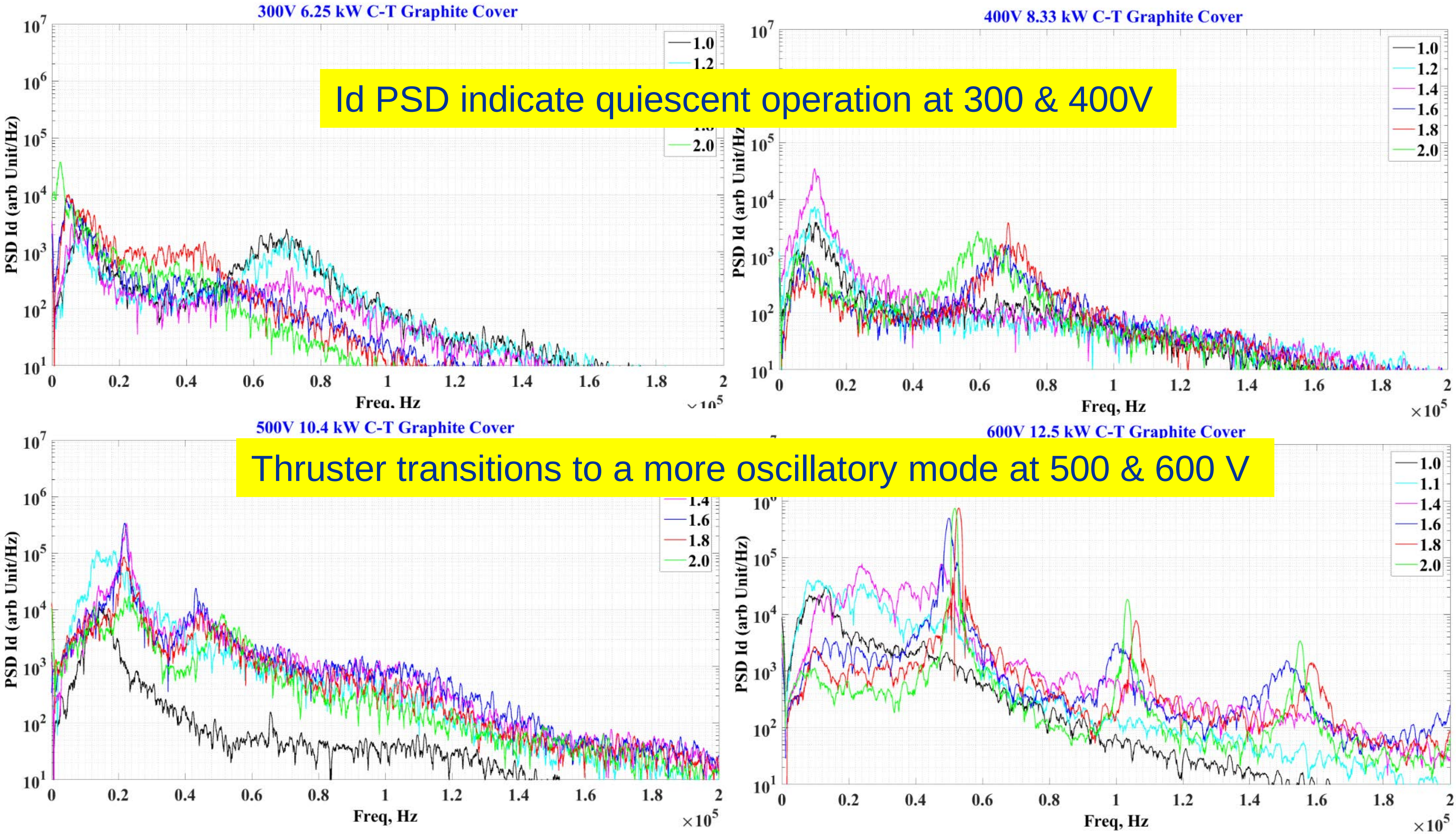
Graphite 208 sccm



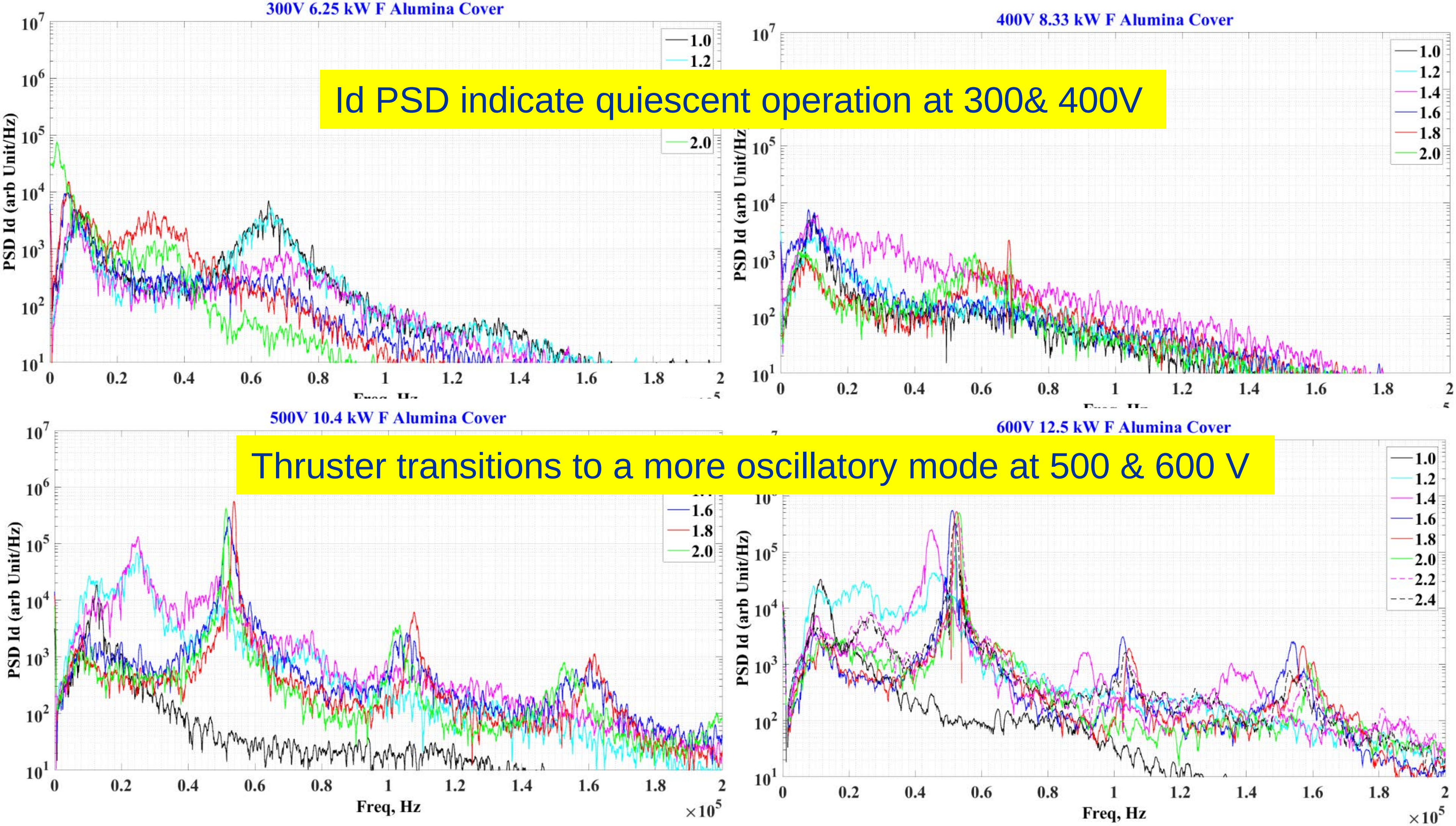
Alumina 205 sccm

- The IVBs for the graphite and alumina configurations show a very similar profile

TDU-1 Stability Graphite: PSD



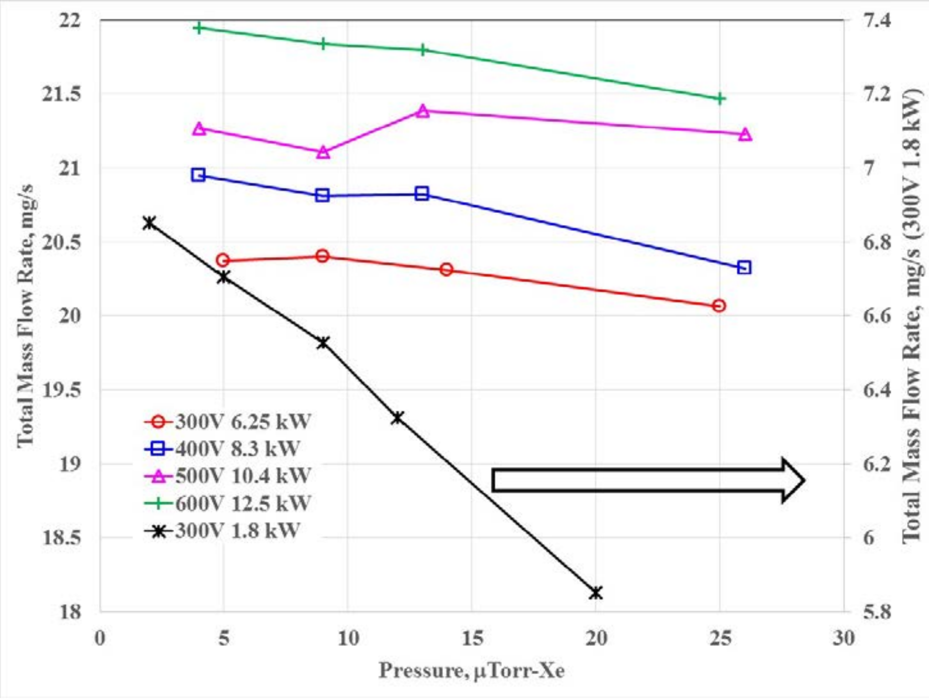
TDU-1 Stability Alumina: PSD



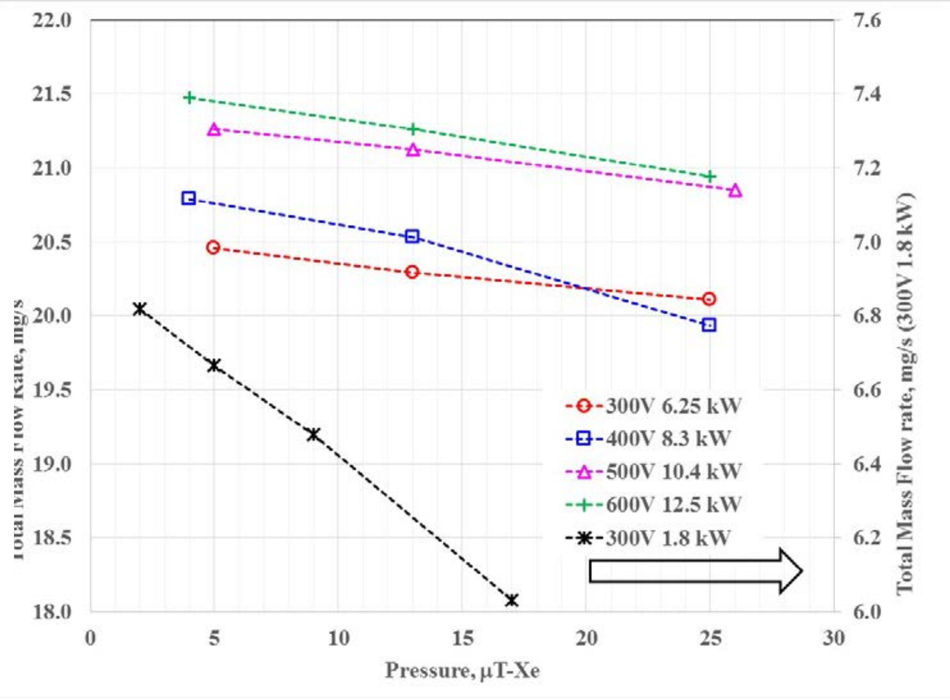
Pressure Background Pressure Effects Characterization

TDU-1 Pressure Effects Test: Graphite & Alumina Mass Flow Rate

Graphite



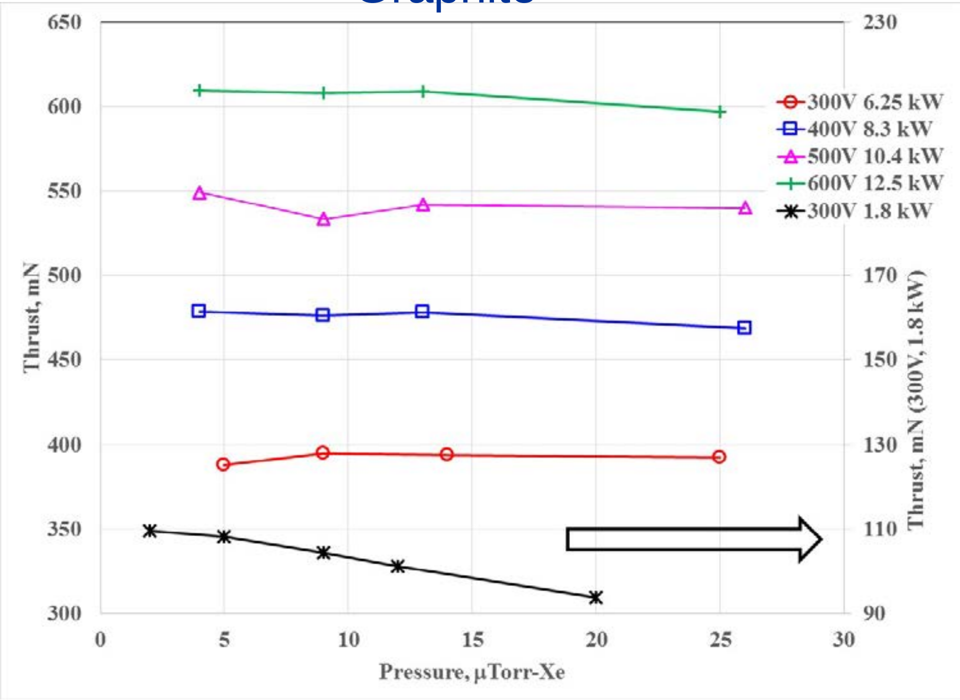
Alumina



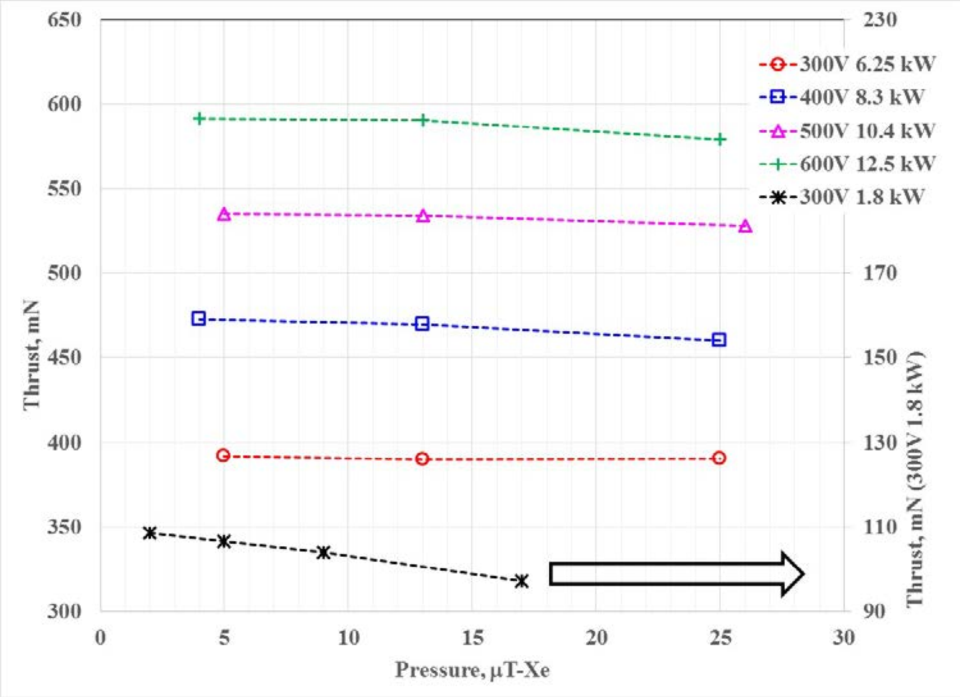
- Due to flow ingestion the anode mass flow rates drops with increased facility background pressure for both the alumina and graphite configurations

TDU-1 Pressure Effects Test: Graphite & Alumina Thrust

Graphite



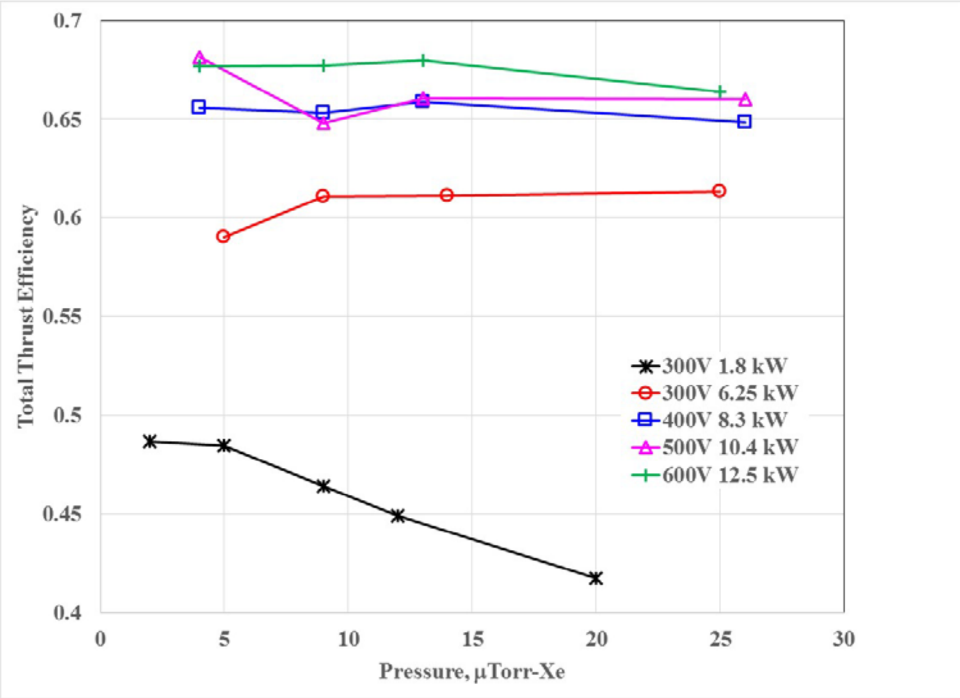
Alumina



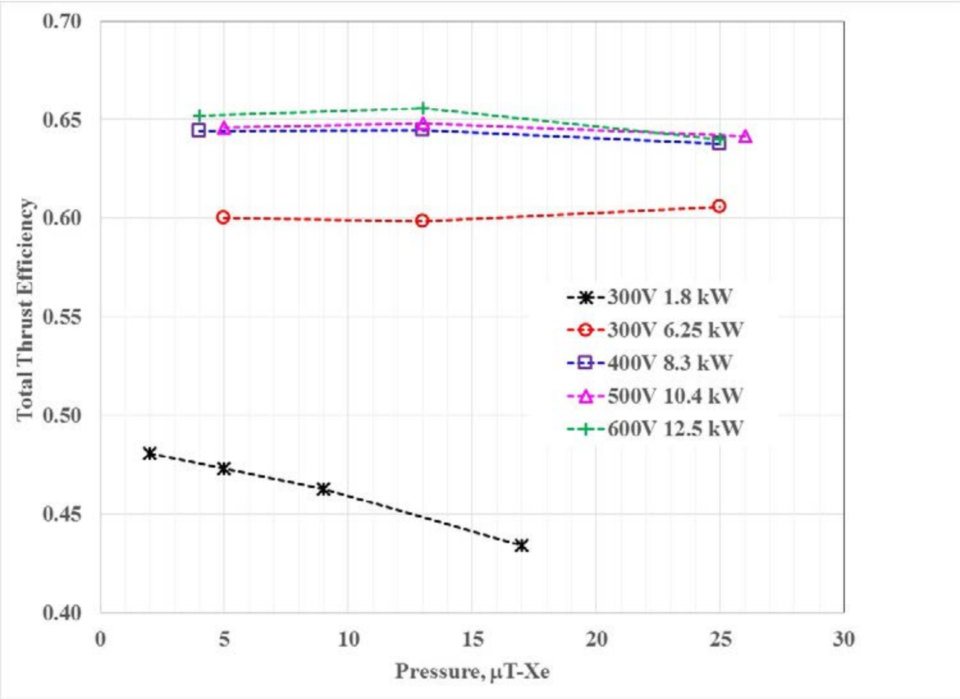
- Thrust changed by less by than 1.5% as the facility pressure was increased except at the lowest flow rate condition of ~65 sccm (3%)
- The thruster thrust variation is more sensitive at lower thruster flow rates

TDU-1 Pressure Effects Test: Graphite & Alumina Thrust Efficiency

Graphite



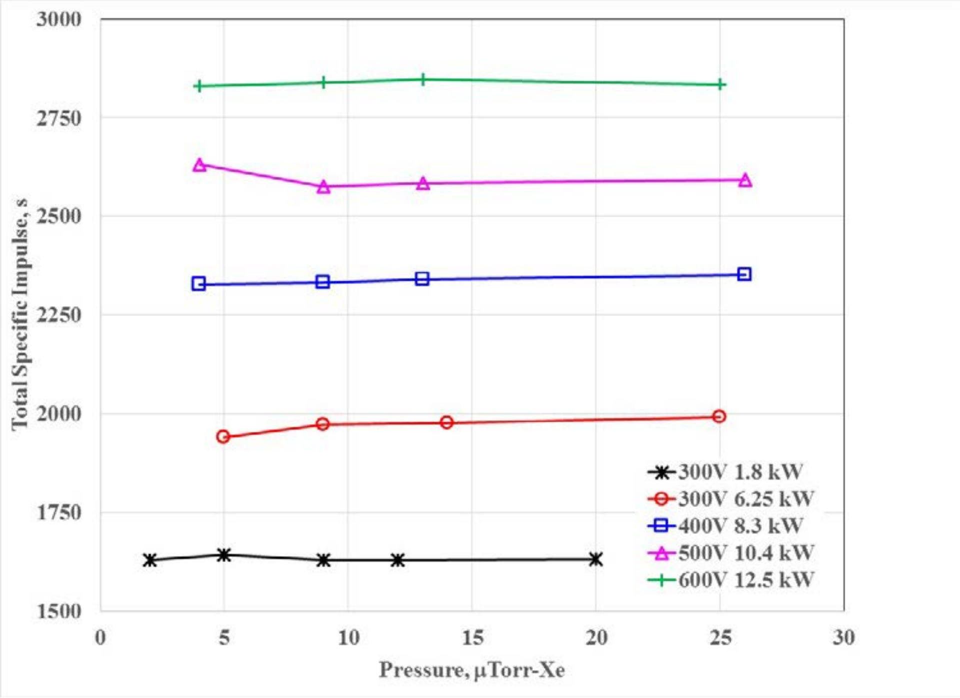
Alumina



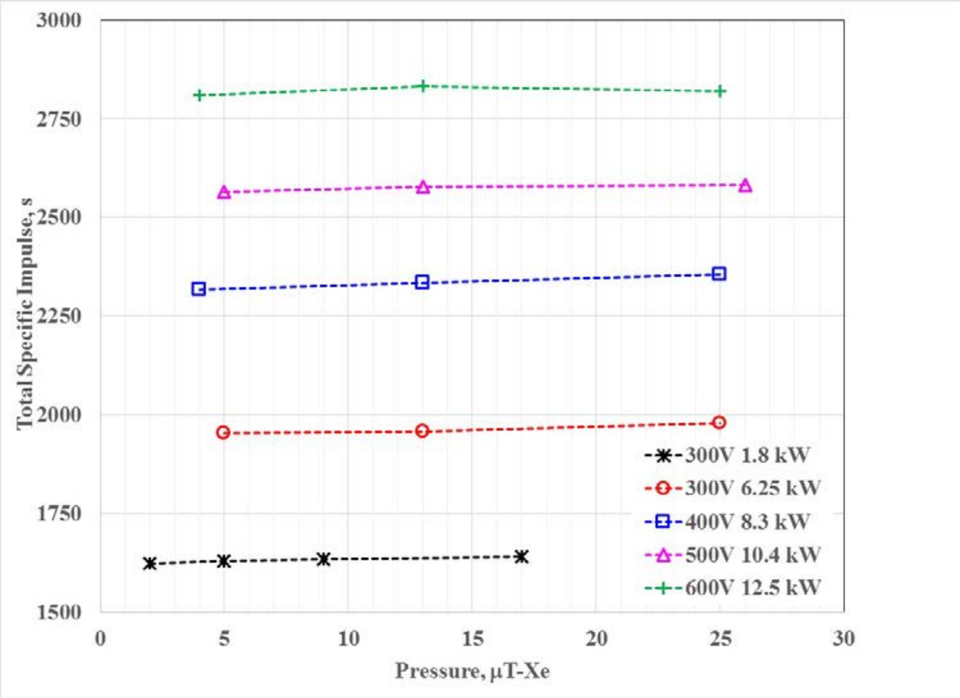
- HERMeS thrust efficiency variation with pressure was within uncertainty of the value except at 65 sccm, where the efficiency dropped with increased facility background pressure.

TDU-1 Pressure Effects Test: Graphite & Alumina Specific Impulse

Graphite



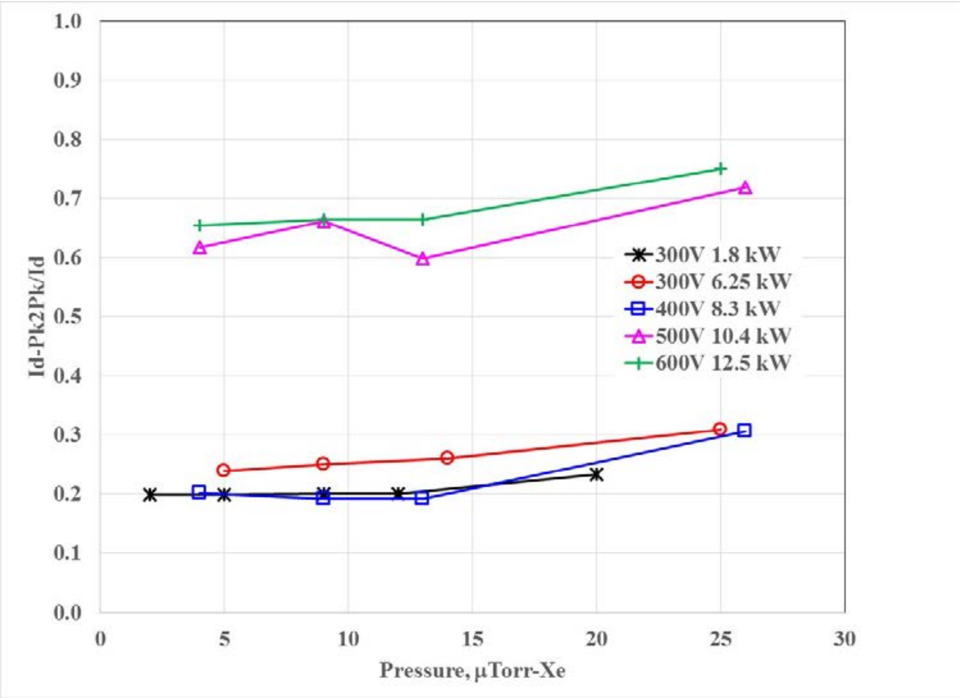
Alumina



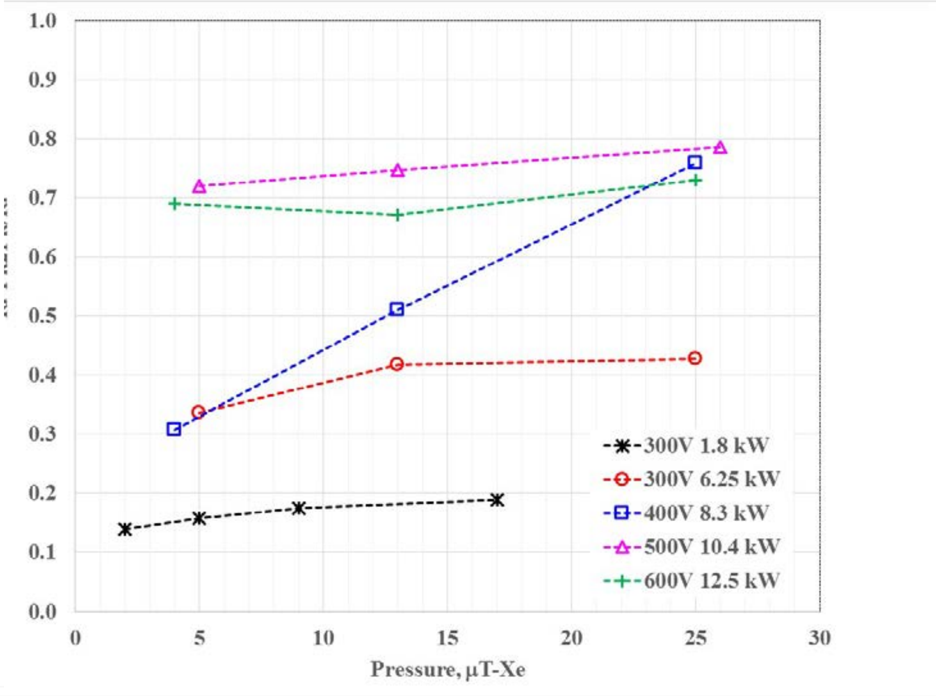
- HERMeS specific impulse variation with pressure was within uncertainty of the value (the reduction in both anode flow rate and thrust offset each other to maintain constant Isp)

TDU-1 Pressure Effects Test: Graphite & Alumina Id-Pk2Pk/Id

Graphite



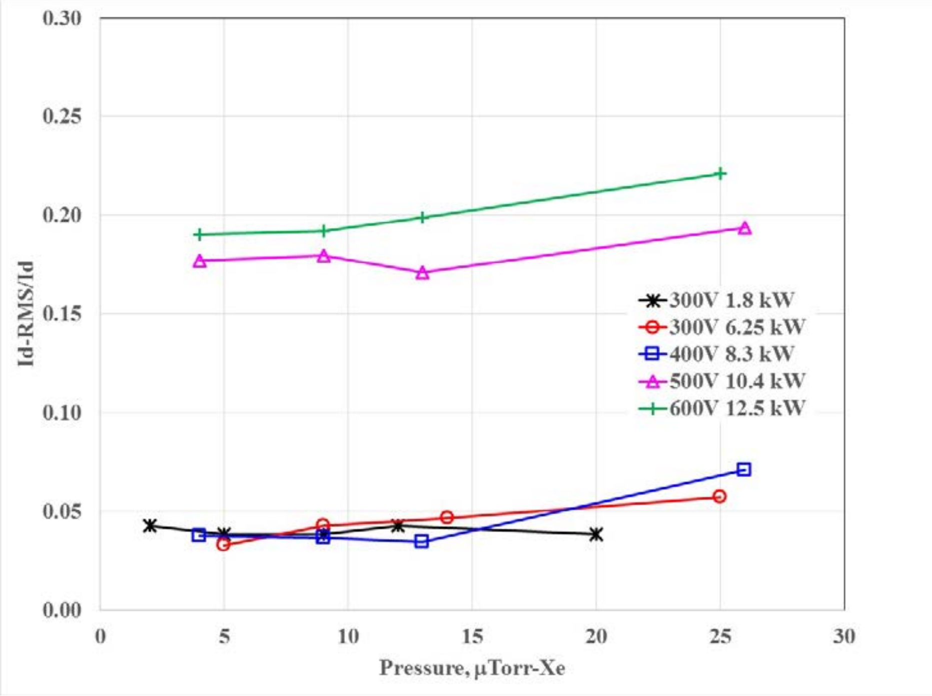
Alumina



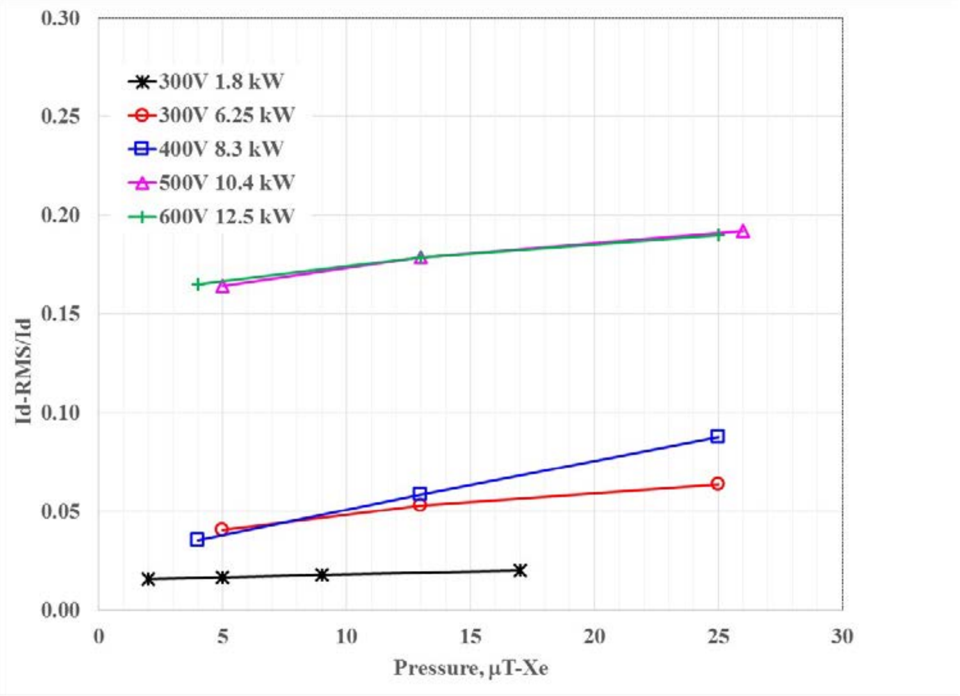
- Discharge oscillation levels increased slightly with facility background pressure
- This observed behavior is different than what has been observed with other Hall thrusters

TDU-1 Pressure Effects Test: Graphite & Alumina Id-rms/Id

Graphite

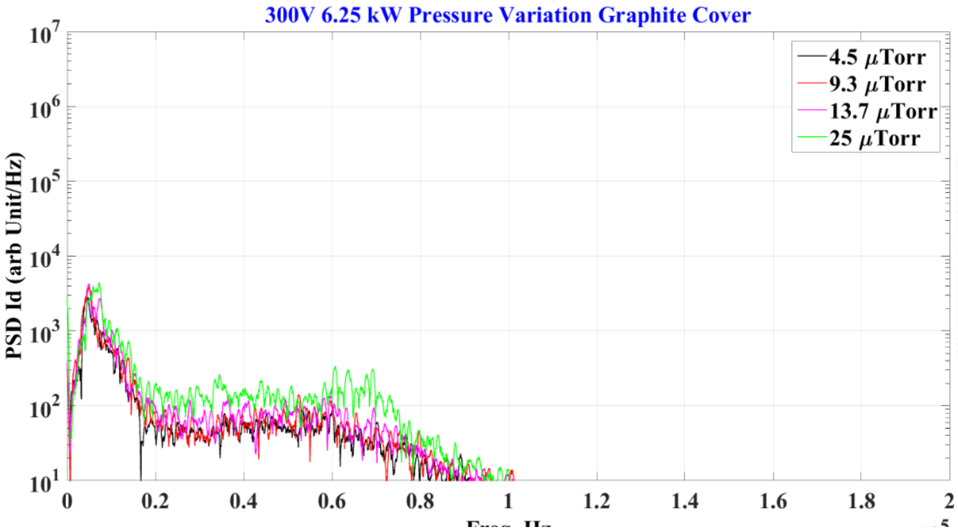


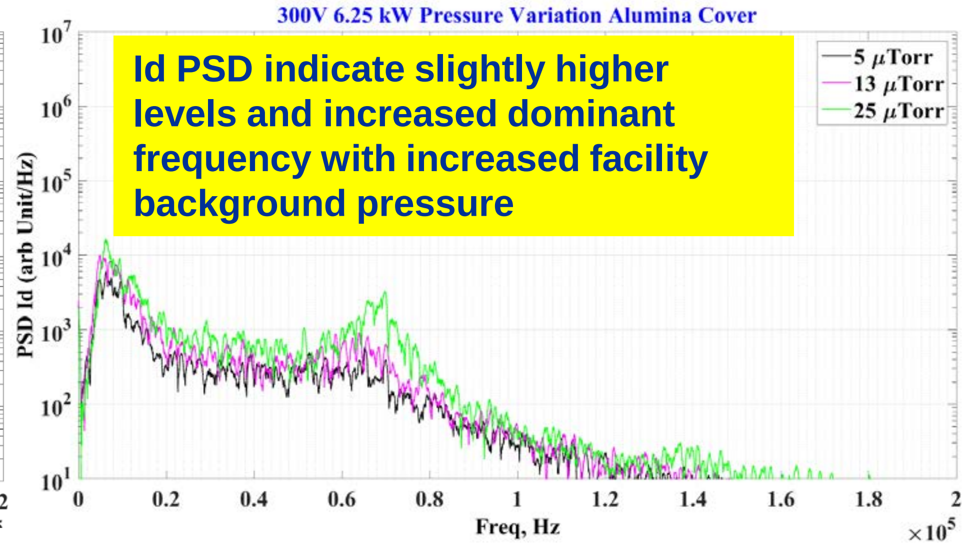
Alumina



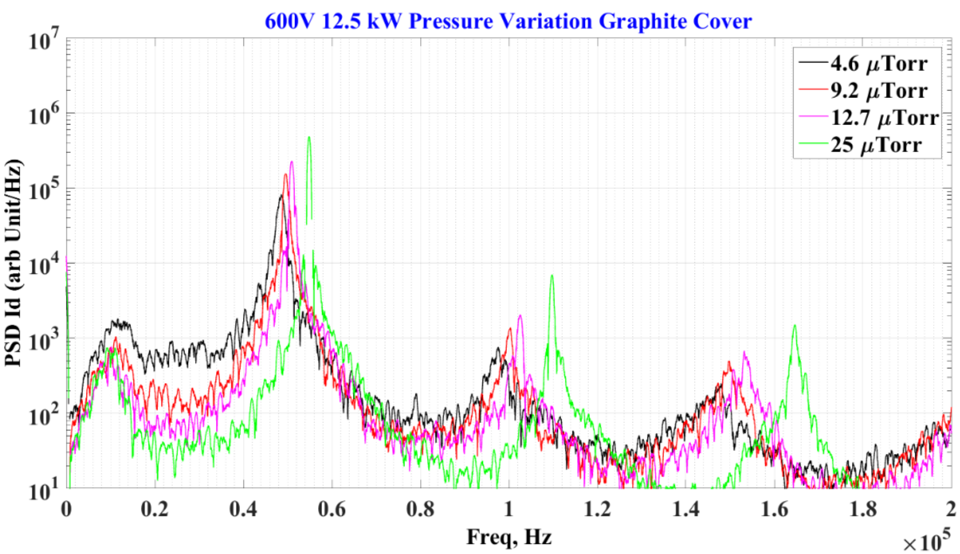
- Discharge oscillation levels increased slightly with facility background pressure
- This observed behavior is different than what has been observed with other Hall thrusters

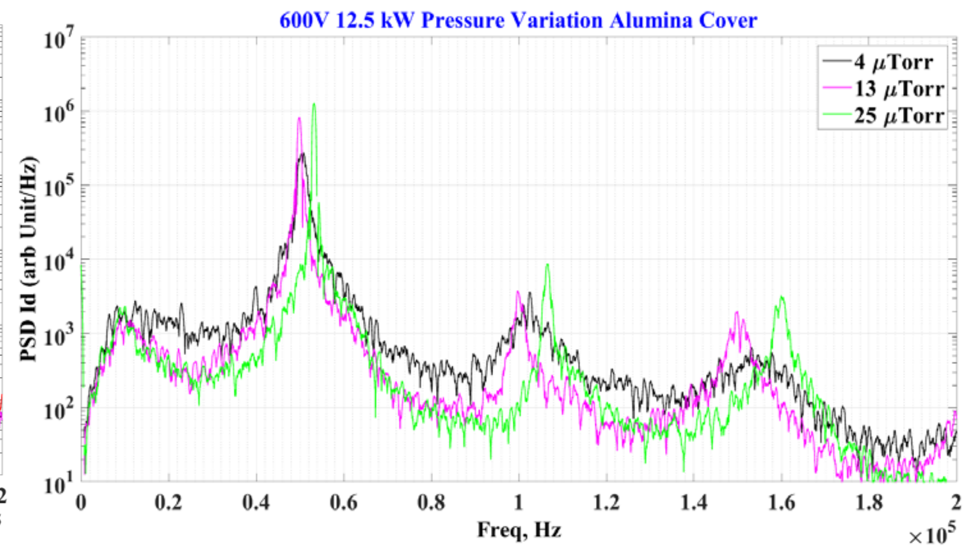
TDU-1 Pressure Effects Test: Graphite & Alumina PSDs



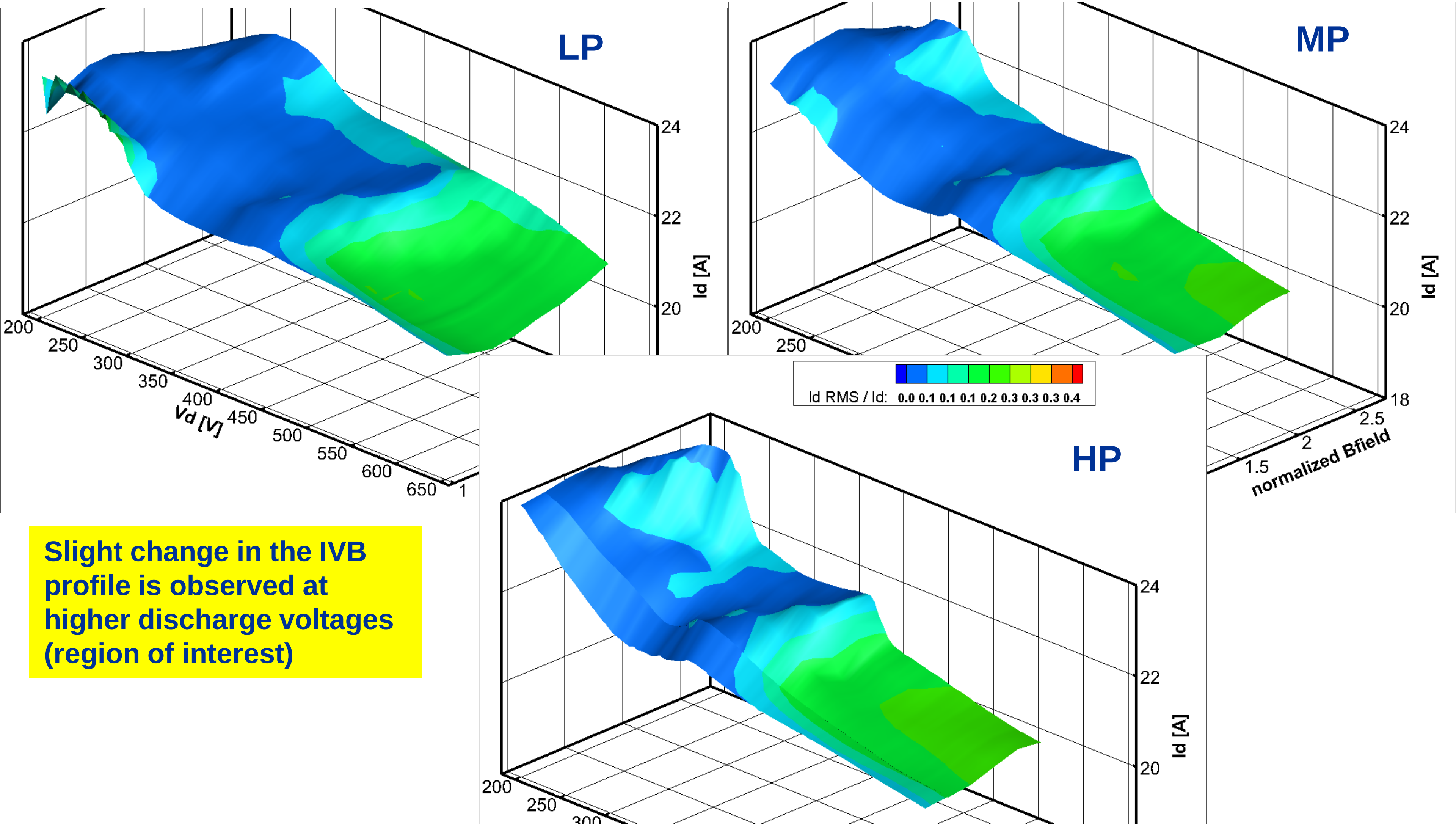


Id PSD indicate slightly higher levels and increased dominant frequency with increased facility background pressure



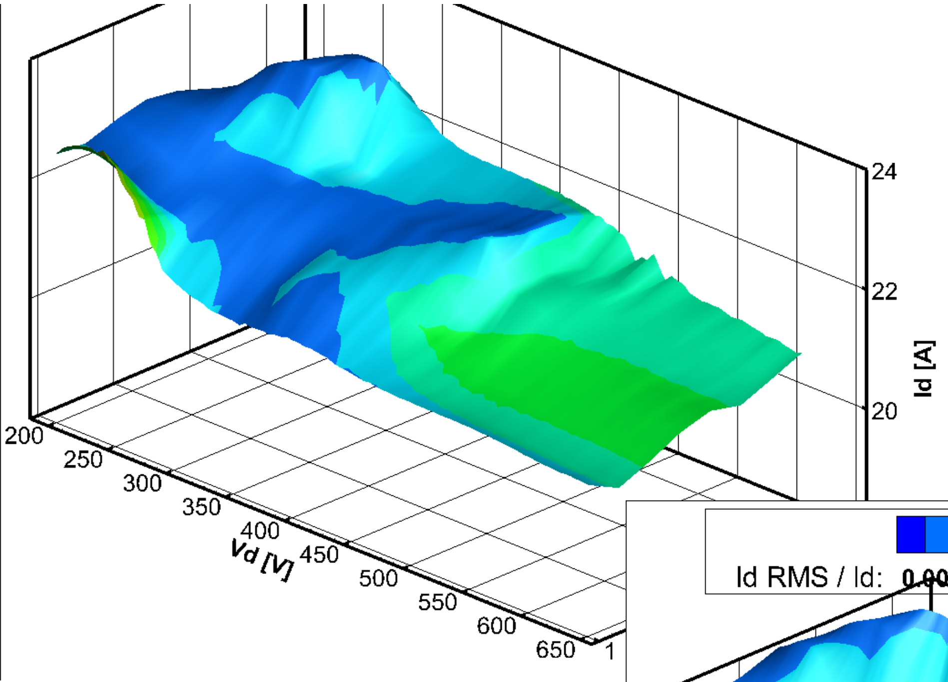


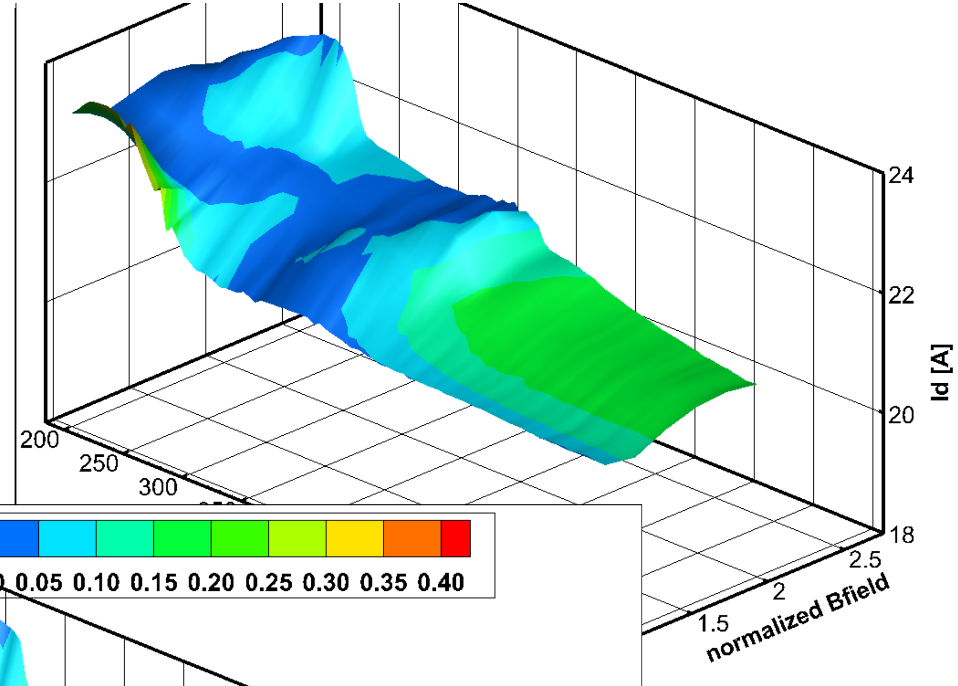
TDU-1 Pressure Effects Test: Graphite IVBs @ 208 sccm

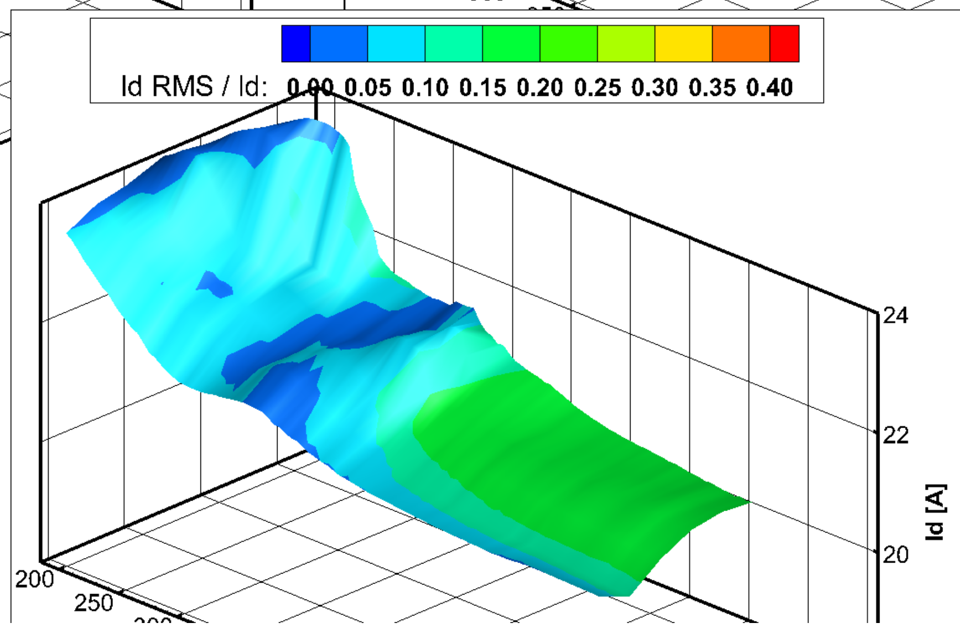


Slight change in the IVB profile is observed at higher discharge voltages (region of interest)

TDU-1 Pressure Effects Test: Alumina IVBs @ 205 sccm







Slight change in the IVB profile is observed at higher discharge voltages (region of interest) with the discharge becoming more oscillatory at higher background pressure

Summary

- NASA GRC has manufactured two HERMeS thruster:
  - TDU-1: Extensively tested at NASA GRC starting in 2015 and continuing in 2016
  - TDU-2: Functional hot fire tests performed at NASA GRC and then shipped to JPL for performance characterization and environmental tests
- In 2016 two configurations of the TDU-1 thruster has undergone extensive performance, stability, and background pressure characterization tests
  - Conducting (graphite) front pole cover configuration with the thruster body electrically tied to the cathode
  - Dielectric (alumina-Al_2O_3) front pole cover configuration with the thruster body floating
- Tests found that the
  - Graphite C-T configuration attained a thrust efficiency and specific impulse of 68% and 2,820 s at 600 V 12.5 kW
  - Alumina F configuration attained a thrust efficiency and specific impulse of 65% and 2,800 s at 600 V 12.5 kW
  - Slightly lower discharge current oscillation were attained with the alumina front pole cover configuration as indicated by the measured I_d Pk2Pk and RMS
  - Magnetic field sweeps of the thruster indicated that there is a wide range of magnetic field settings that can result in reliable sustained efficient thruster operation
  - Id PSDs indicated that the thruster (for both configurations) operates in a mostly quiescent mode at discharge voltages of 300 and 400 V and then transitions to a more oscillatory mode at 500 and 600 V

Summary

- Tests at elevated facility background pressure were performed and indicated
  - The TDU-1 thruster discharge current oscillation levels were lowest at the lowest facility background pressure
  - Tests indicated that the HERMeS thruster performance was more sensitive to facility background pressure variations when operated at low flow rate
    - At a flow rate of ~208 sccm the performance of the thruster, for both configurations, did not change significantly as the facility background pressure was varied
    - At a flow rate of 65 sccm the performance of the thruster, for both configurations, changed as the facility background pressure was varied
  - Increasing the facility background pressure resulted in increased discharge current oscillation levels and a slight increase in the dominant frequency
  - No significant change in the IVBs was observed at the higher discharge voltage when the facility background pressure was increased
- Future work includes:
  - Completion of TDU-1 thruster data analysis
  - Additional detailed facility background pressure investigation at flow rates lower than ~200 sccm
  - Investigation of the effect of the thruster magnetic field topology on thruster performance, stability, and wear

Acknowledgments

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- We thank Christopher M. Griffiths, Lauren K. Clayman, James L. Myers, Li C. Chang, and Dale A. Robinson of the NASA Glenn Research Center and Benjamin Jorns, James E. Polk, Michael J. Sekerak, Ryan Conversano of the Jet Propulsion Laboratory for work on the SEP TDM HERMeS Hall thruster.
- We thank Michael Swiatek, Chad Joppeck, Kevin L. Blake, George P. Jacynycz, Thomas A. Ralys, and Terrell J. Jensen for the fabrication, assembly of the test setup, and operation of the vacuum facility.